



Max-Planck-Institut
für Radioastronomie



Fast Fourier Transform Spectrometer (FFTS)

Past, Present and Future

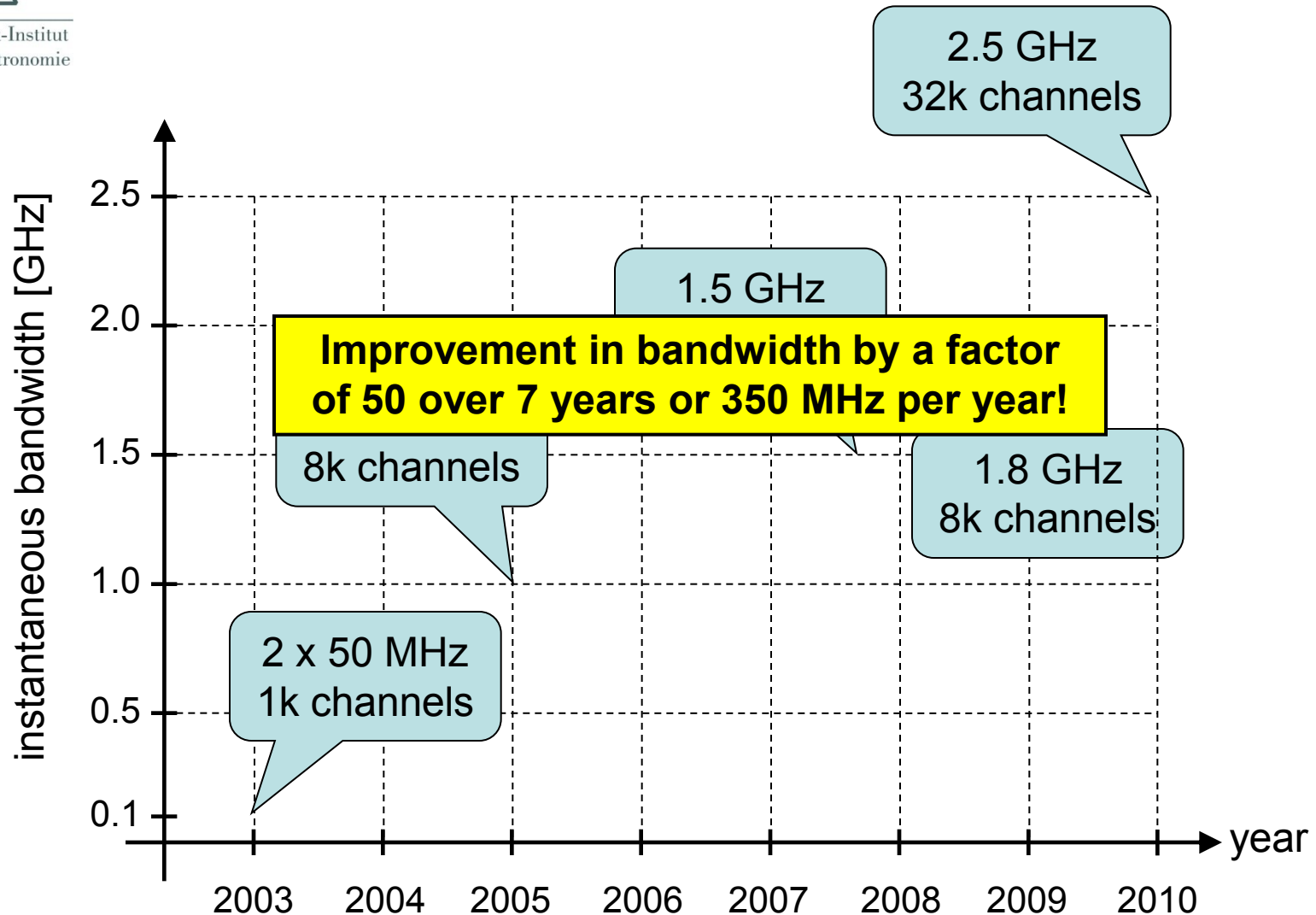
Bernd Klein

*Max-Planck-Institut für Radioastronomie, Bonn
- Germany -*



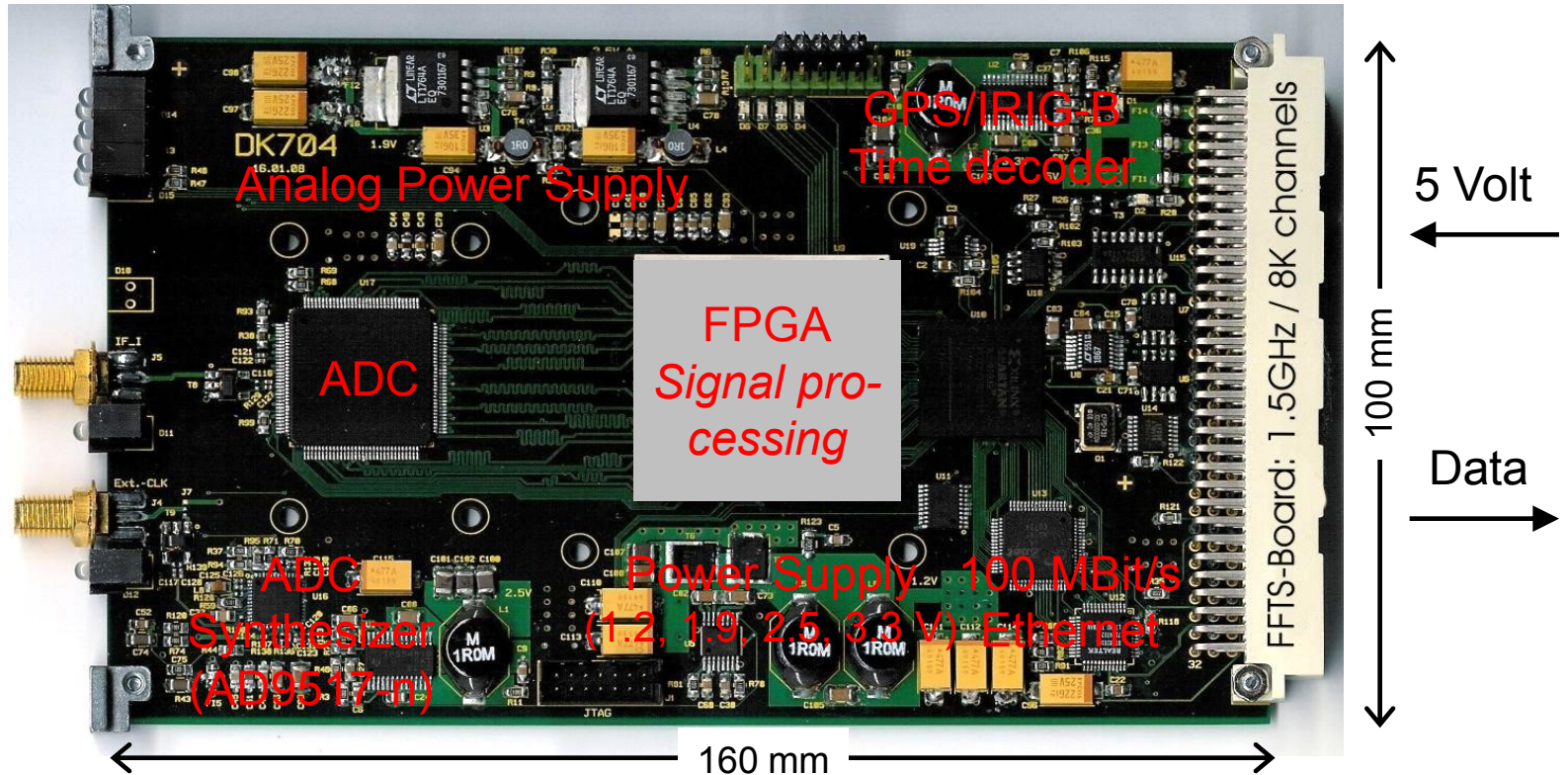


FFTS :: A short "history"





FFTS :: 1.5 GHz bandwidth Board

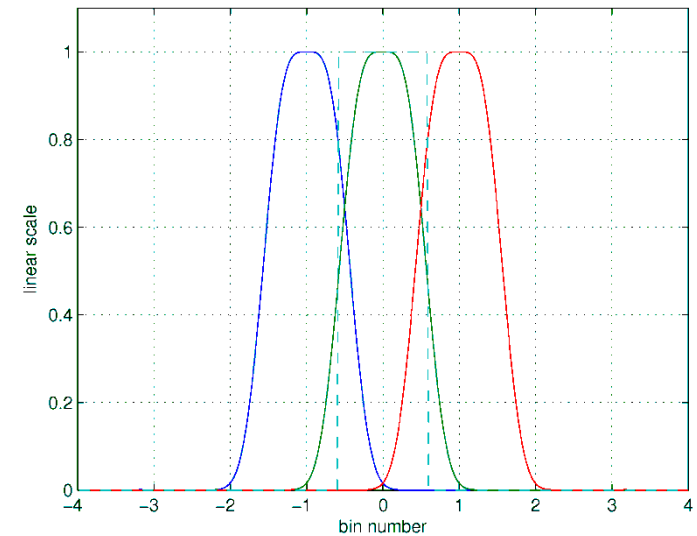
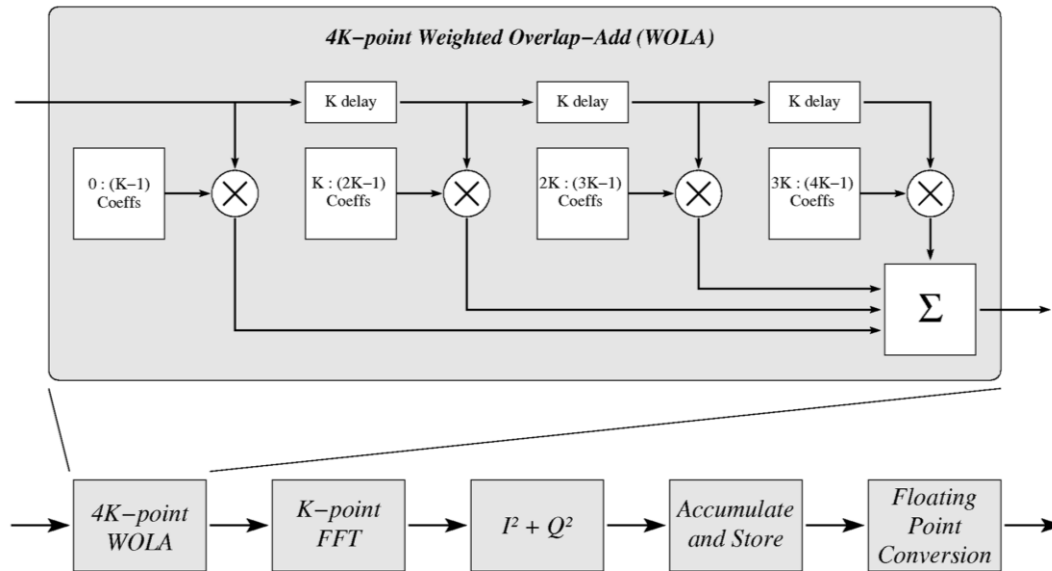


- Instantaneous bandwidth: 0.1 – 1.8 GHz
- Spectral resolution @ 1.5 GHz: 212 kHz
- Calibration- and aging free digital processing



FFTS :: Signal Processing

Unlike the conventional windowed-FFT processing, a more efficient polyphase pre-processing algorithm has been developed with significantly reduced frequency scallop, less noise bandwidth expansion, and faster sidelobe fall-off.



Frequency response of the optimized FFT signal processing pipeline

Equivalent noise bandwidth = 1.16 x frequency spacing



FFTS :: *FPGA configurations*

Today, implemented FFTS board / FPGA configurations are:

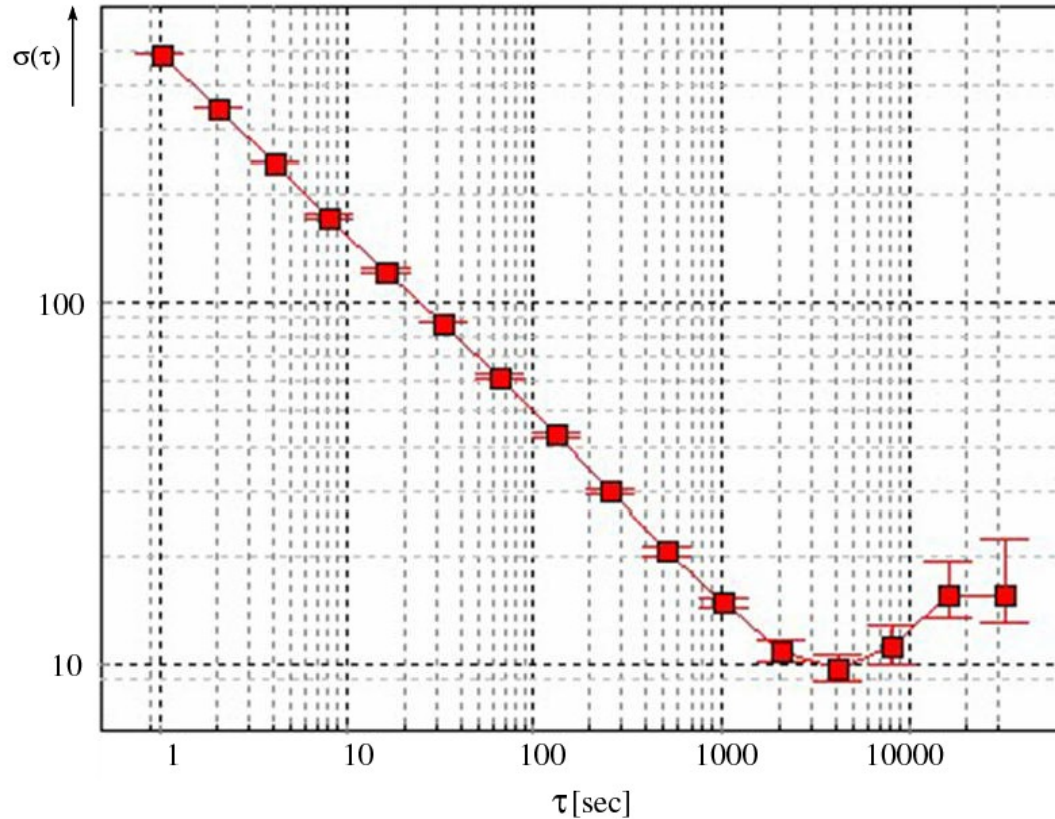
- 1 x 1.5 GHz bandwidth, 1 x 8192 spectral channels, ENBW: 212 kHz (default core)
- 1 x 1.8 GHz bandwidth, 1 x 8192 spectral channels, ENBW: 255 kHz

- 1 x 750 MHz bandwidth, 1 x 16382 spectral channels, ENBW: 53 kHz
- 1 x 500 MHz bandwidth, 1 x 16384 spectral channels, ENBW: 35 kHz
- 1 x 100 MHz bandwidth, 1 x 16384 spectral channels, ENBW: 7 kHz
- 1 x 50 MHz bandwidth, 1 x 16384 spectral channels, ENBW: ~4 kHz

The Equivalent Noise Bandwidth (ENBW) is the width of a fictitious rectangular filter such that the power in that rectangular band is equal to the (integrated) response of the actual filter.



FFTS :: Stability



The spectroscopic Allan variance between two 1 MHz broad channels, separated by 800 MHz within the band, was determined to be stable on a timescale of ~ 4000 s.



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AFFTS :: Array-FFTS for APEX



Bandwidth: $32 \times 1.5 \text{ GHz} = 48 \text{ GHz}$ (option 58 GHz)
Spec. channels: $32 \times 8\text{k} = 256\text{k}$ channels @ 212 kHz



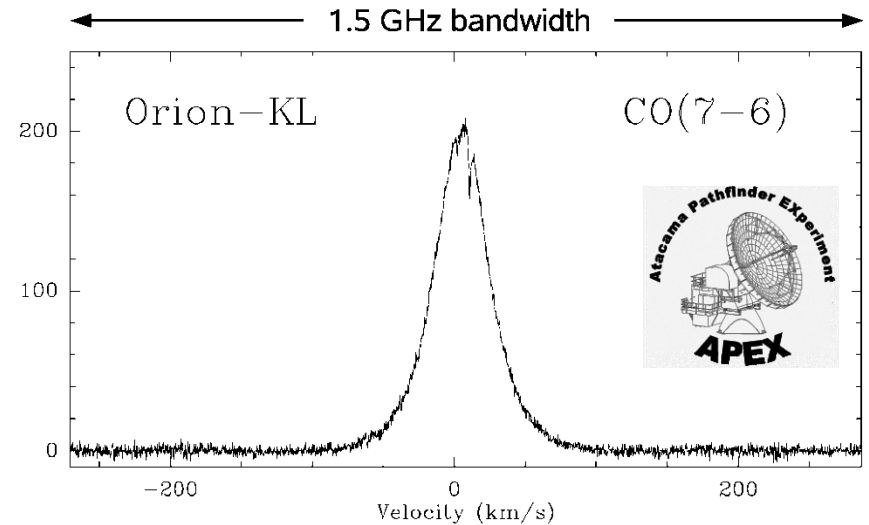
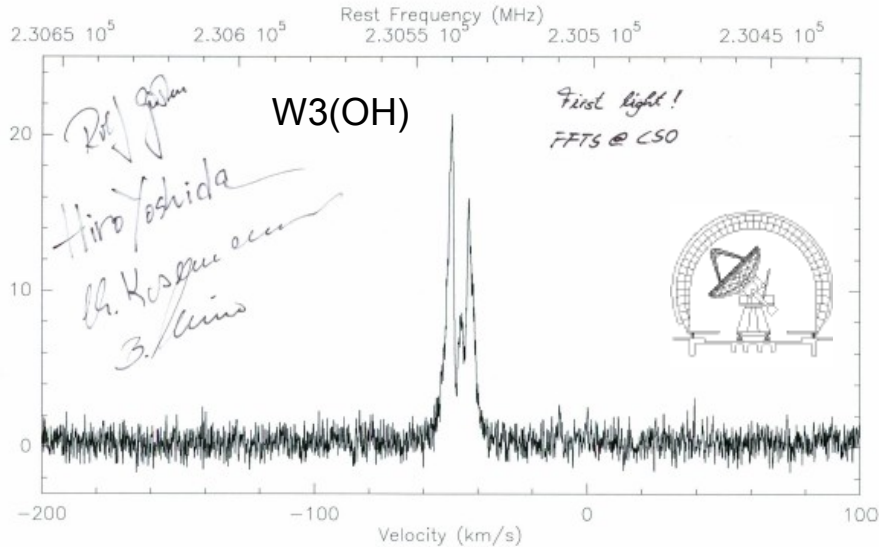
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FFTS :: in world-wide use

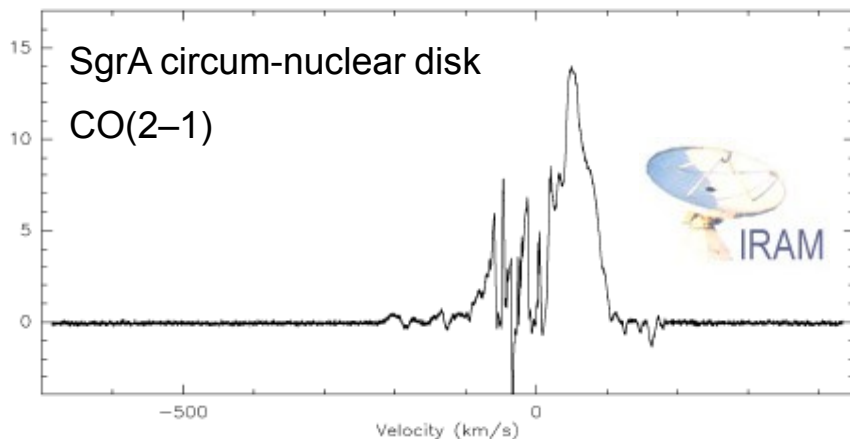
The superior performance, high sensitivity and reliability of MPIfR FFT spectrometers has now been demonstrated at many telescopes world-wide.



Spectrum towards Orion-KL. The high-excitation CO(7-6) transition at 806 GHz was observed with the central pixel of the CHAMP+ array.

Further details:

- B. Klein, et al., Proceedings of the 19th ISSTT, Groningen 28-30 April 2008
- <http://www.mpifr-bonn.mpg.de/staff/bklein>





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FFTS :: Contact, Distribution

Contact:

For further information about the MPIfR FFT spectrometer, future developments and applications, please contact Bernd Klein (bklein@mpifr.de) or Rolf Güsten (rguesten@mpifr.de) at the Max-Planck-Institut für Radioastronomie in Bonn, Germany.



Distribution:



<http://www.radiometer-physics.de>

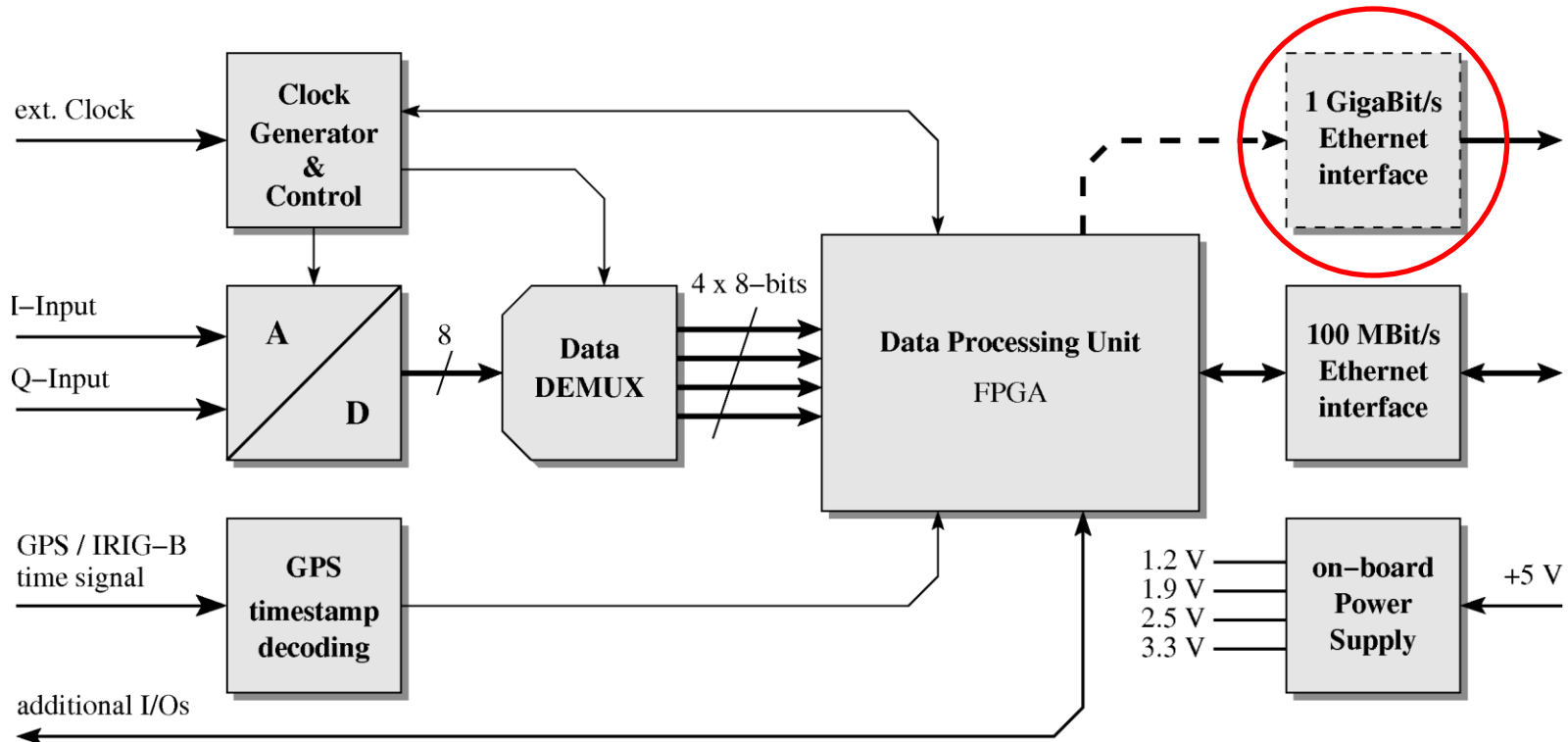




EFFTS :: *The Effelsberg FFTS*

Applications:

- **Spectroscopy** :: 16 x 100 - 500 MHz bandwidth, 8192 and 16384 channels
- **Pulsar Search** :: 16 x 250 MHz bandwidth, 512 channels, 32/64 μ s dumping

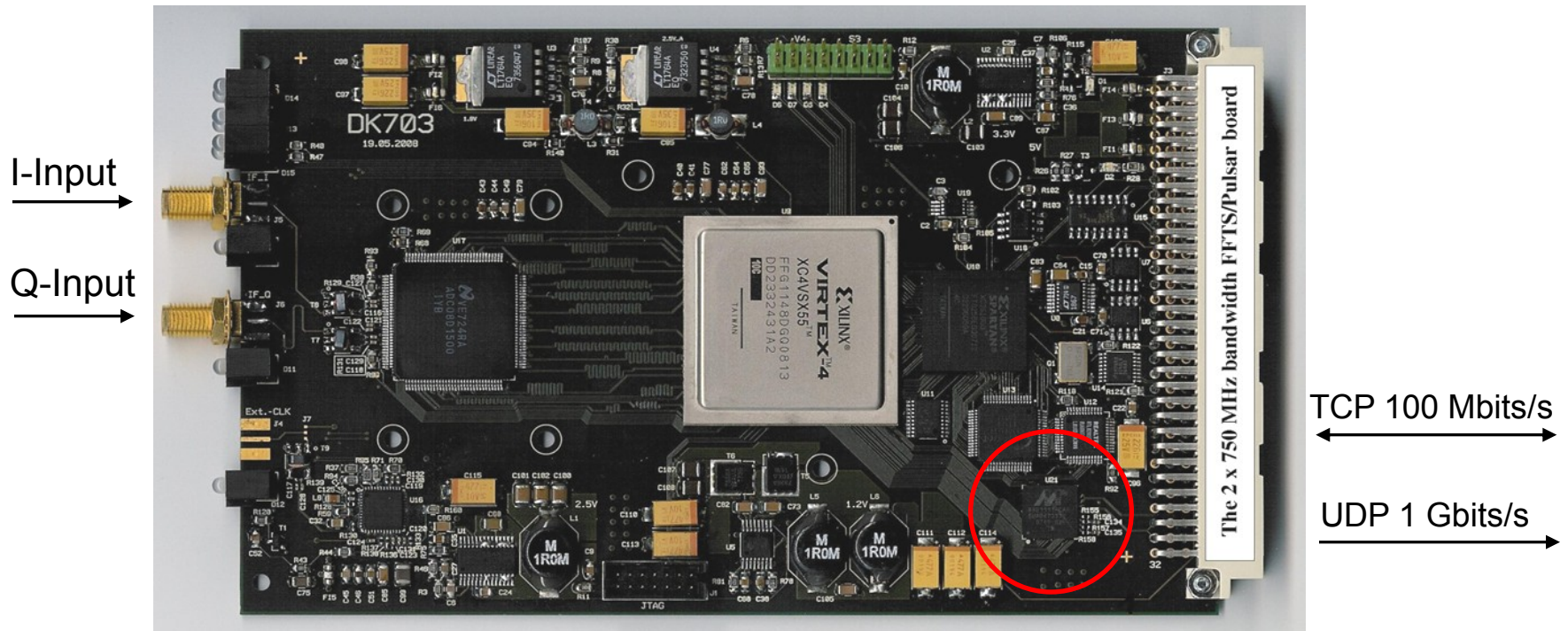




EFFTS :: *The analyzer board*

Board modifications:

- **Dual input ADC** :: National ADC08D1500, 2 x 750 MHz bandwidth
- **GigaBit Ethernet**:: Marvell 88E1111, UDP: 85 MBytes/sec cont.



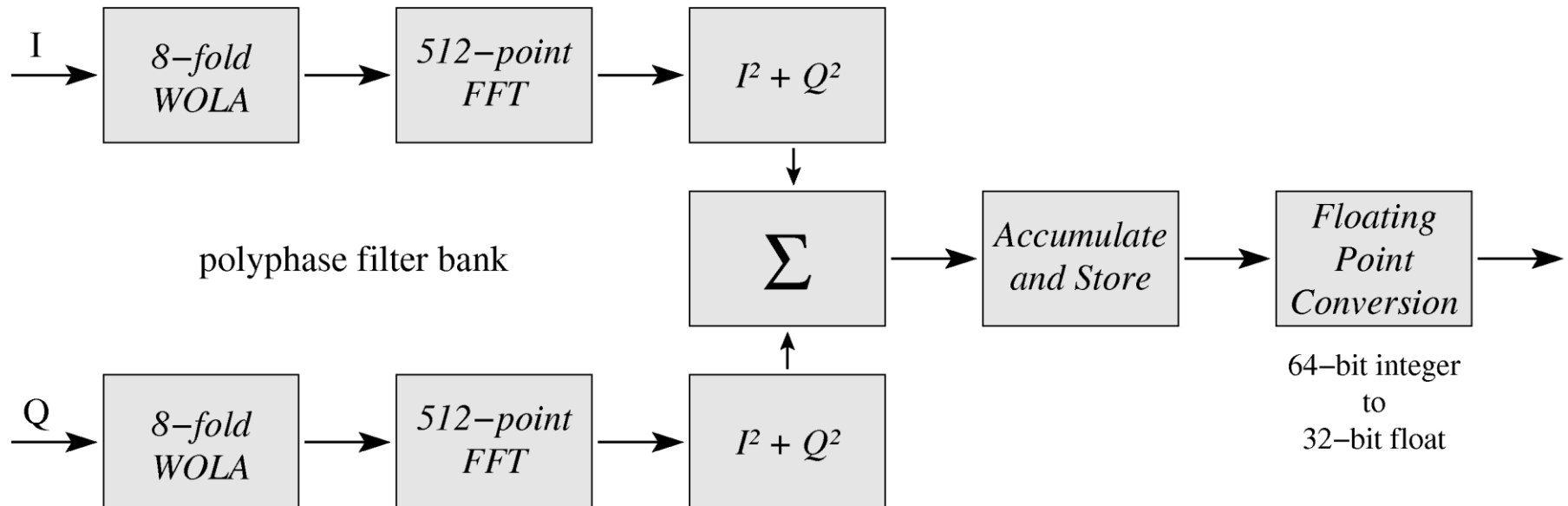
Marvell GigaBit chip



EFFTS :: *pulsar signal processing*

Performance:

- **FPGA processing** :: 250 MHz bandwidth & 8-tab polyphase filterbank with 512 channels, ENBW: 515 kHz
- **Dump time [μs]** :: 32, 64 or 128, 16 x 512 channels (32-bit float)
1k Bytes tail (dump counter, GPS/IRIG-B time,...)
- **Data rate @ 32 μs** :: ~64 MBytes/sec





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EFFTS :: *The Effelsberg FFTS*

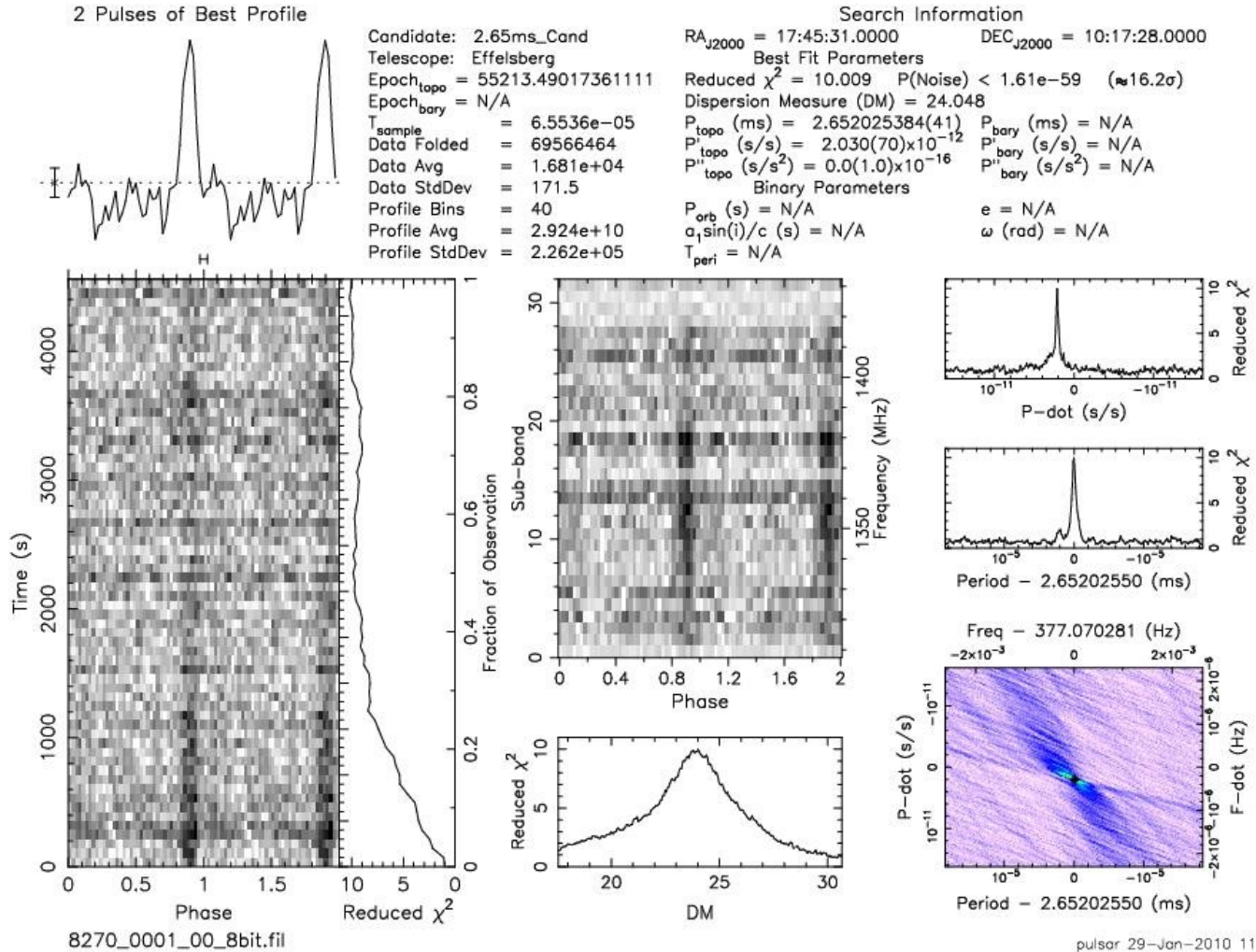


Norbert Tacken



EFFTS :: Pulsar discovery

PSR J1745+10 - first MSP discovery in Effelsberg, P = 2,65 ms

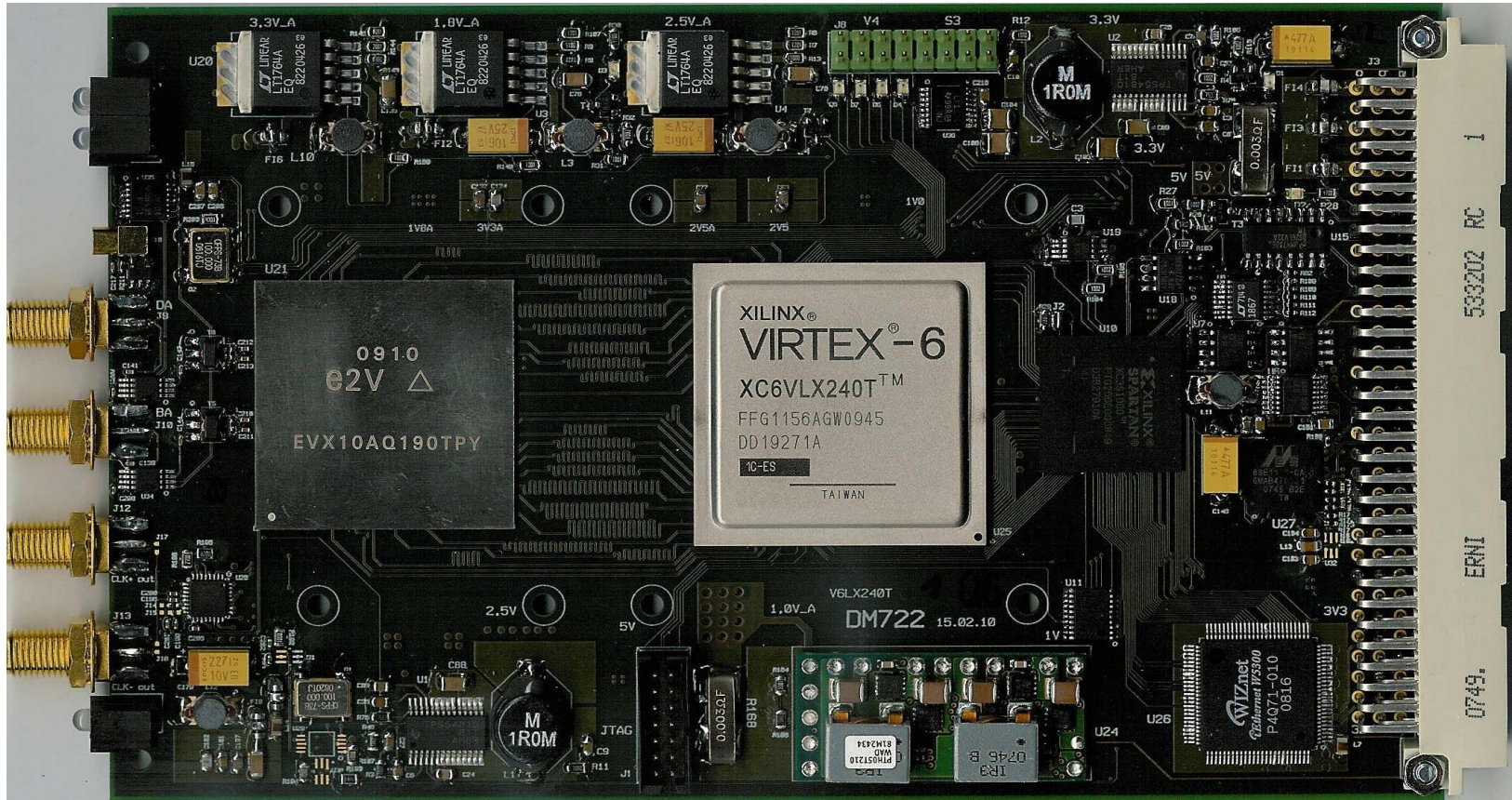




XFFTS :: *The newest board*



XFFTS: 2.5 GHz bandwidth / 32768 channels (ENBW 88.5 kHz)



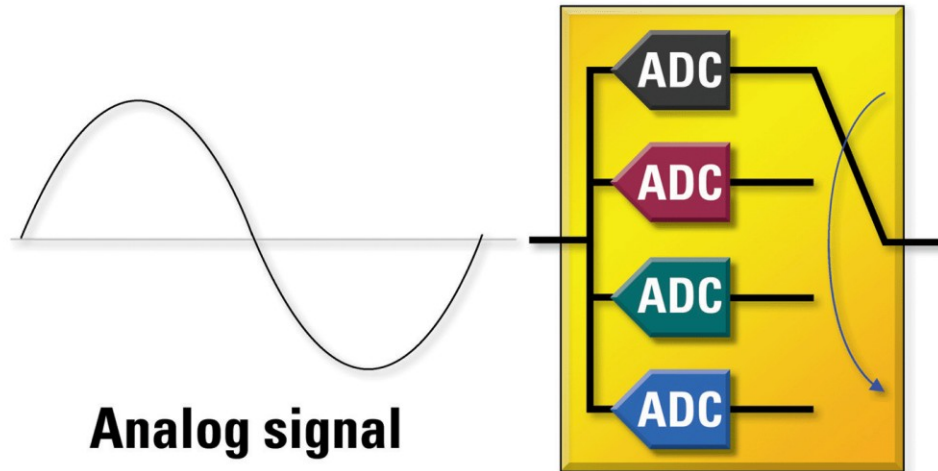
**E2V 5 GS/s 10-bit ADC, XILINX Virtex-6 LX240T
[40 nm, 1.0 volt core voltage, >240'000 logic cells, 768 DSP48 slices]**



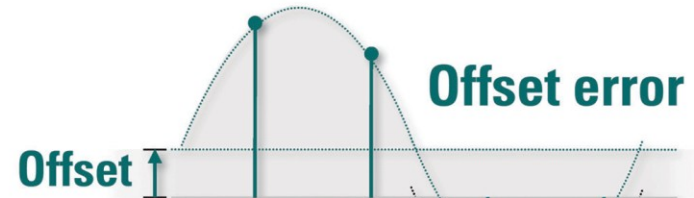
XFFTS :: ADC interleaving

ADC: e2v 10-Bit, 4 x 1.25 GS/s

e2v scientific instruments

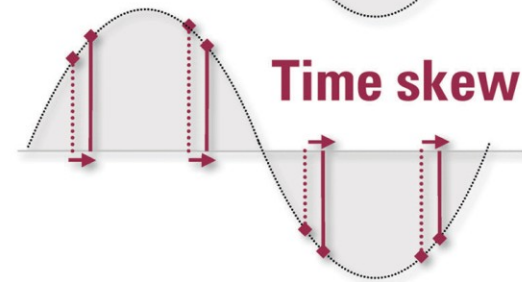


Analog signal

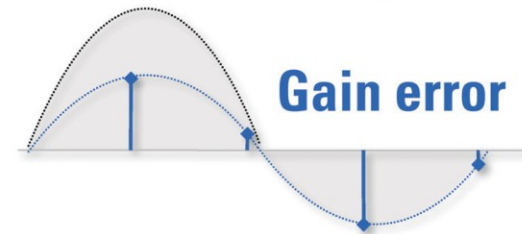


Offset error

Offset



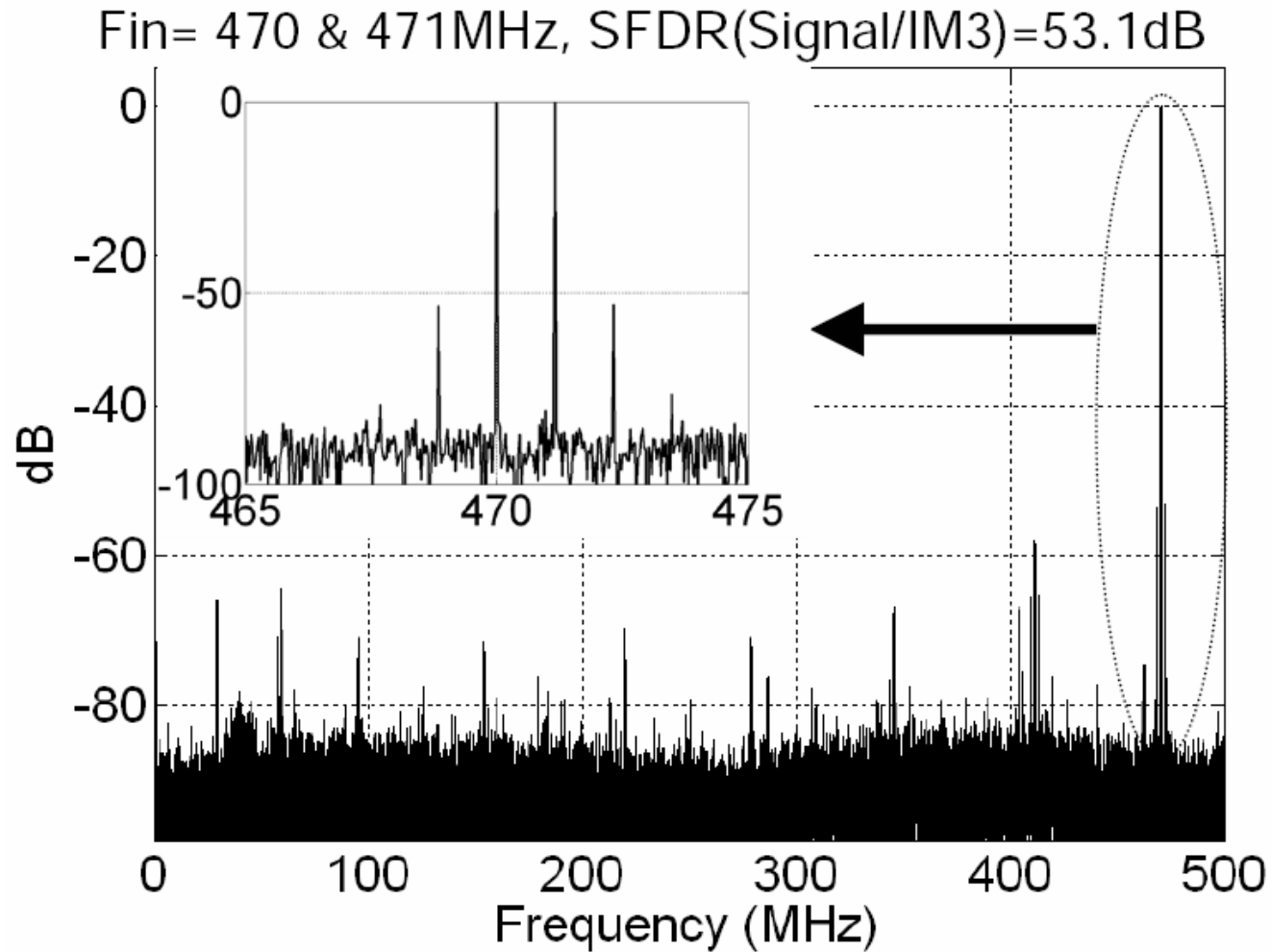
Time skew



Gain error



XFFTS :: *ADC interleaving*



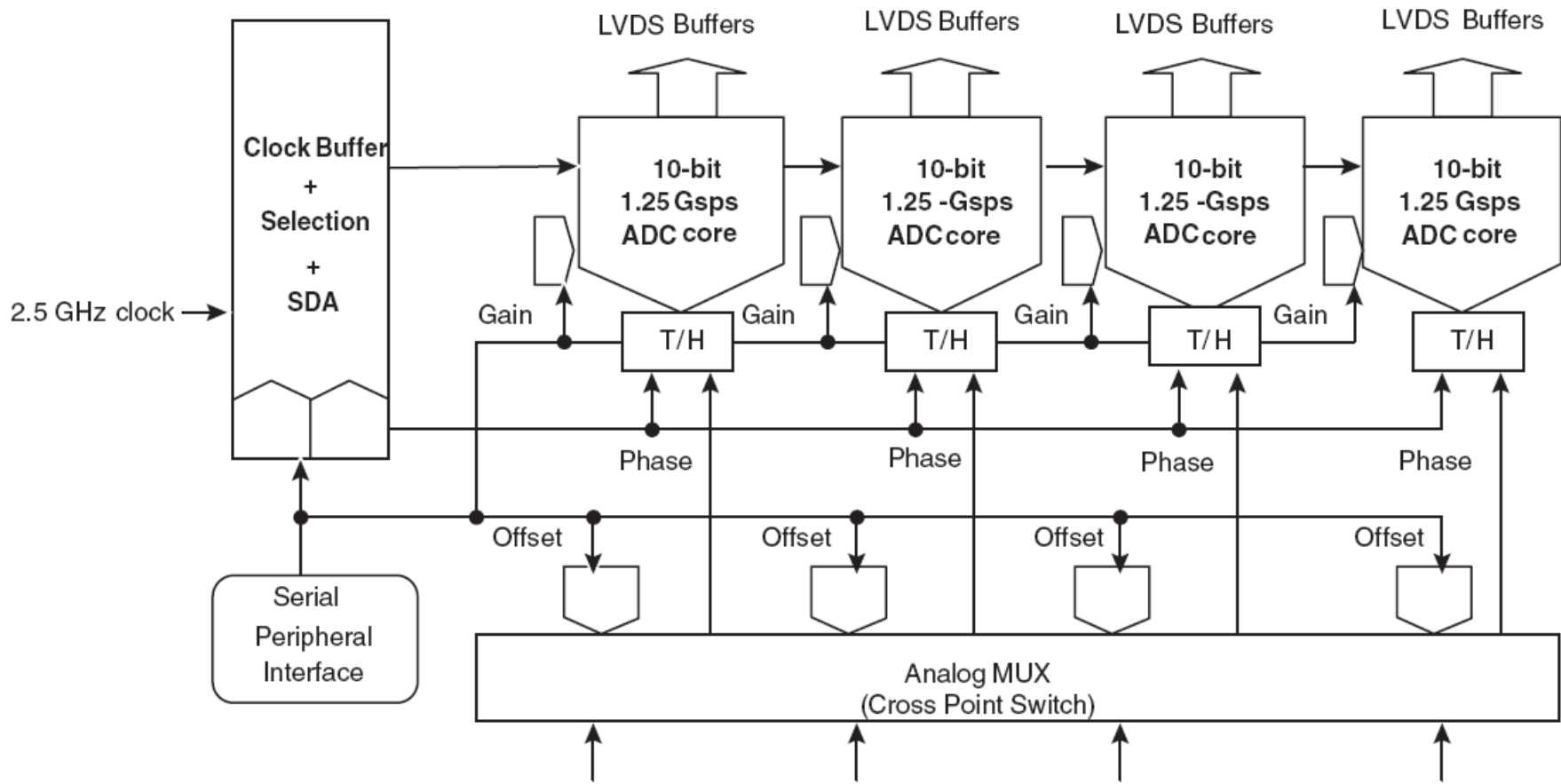


XFFTS :: ADC interleaving



ADC: e2V 10-Bit, 4 x 1.25 GS/s

e2v scientific instruments

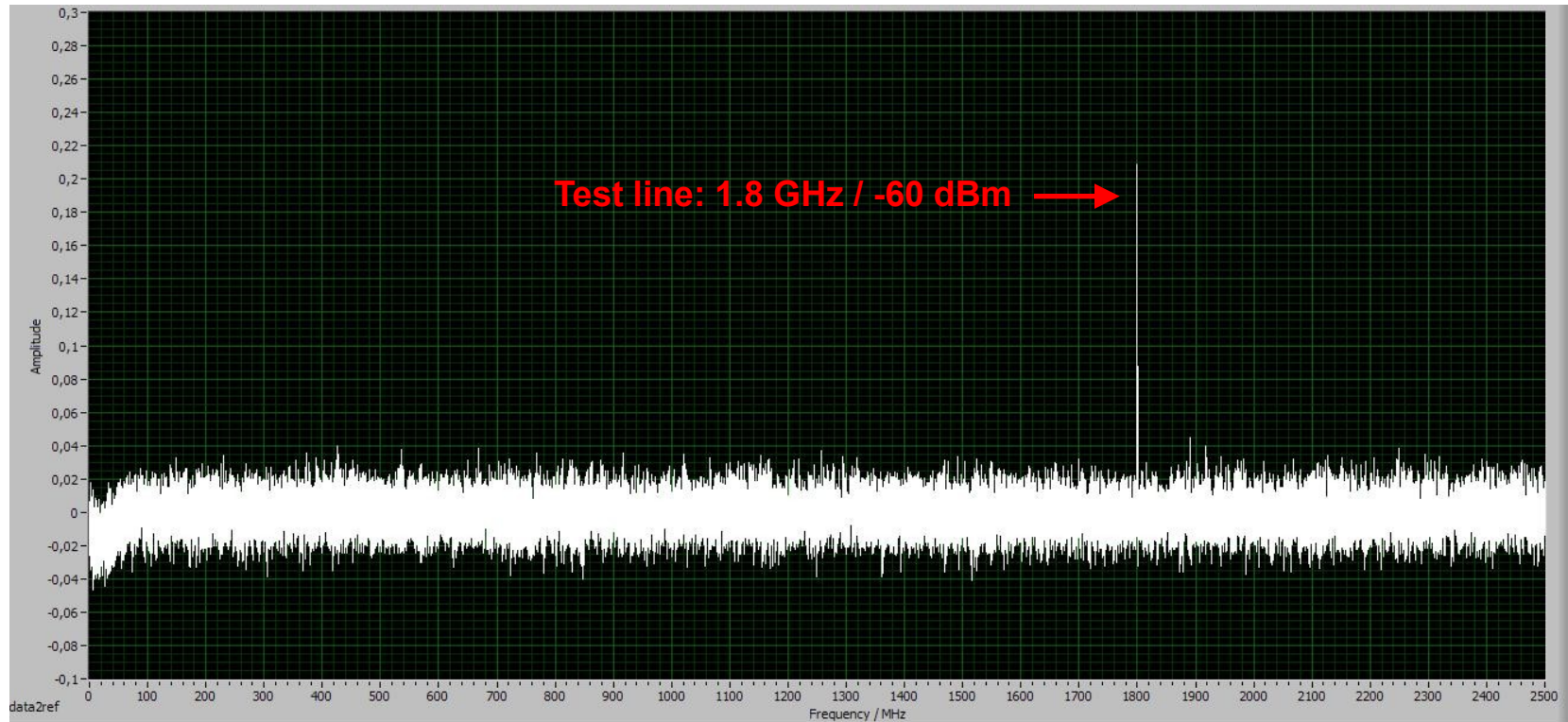


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XFFTS :: ADC interleaving

XFFTS: 2.5 GHz bandwidth / 10-bit / 32768 channels (ENBW 88.5 kHz)



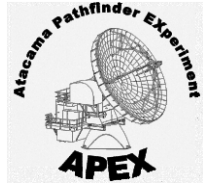
← 2.5 GHz instantaneous bandwidth →



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XFFTS @ APEX :: IF-Processor

DIGITALLABOR
www.digitallabor.com



XIF: 2 x 4 GHz @ 6 GHz center frequency \Rightarrow 4 x 2.5 GHz (XFFTS)



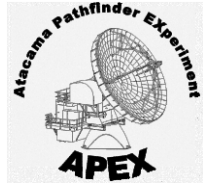
Installation & Commissioning: June 2010



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XFFTS @ APEX

DIGITALLABOR
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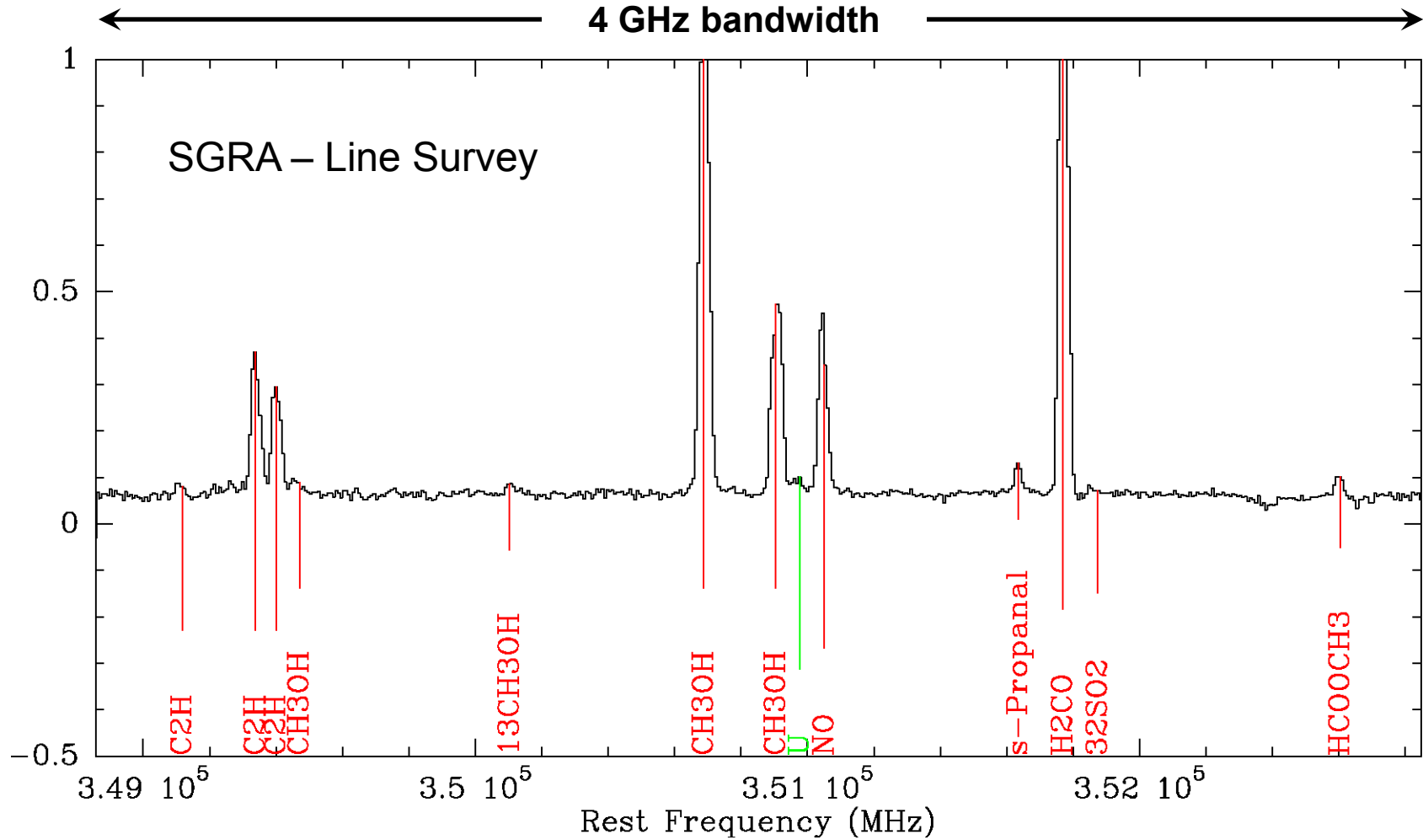
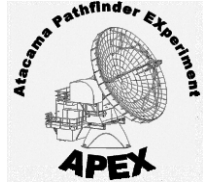
XFFTS: 4 x 2.5 GHz, 4 x 32768 spectral channels, ENBW: 88,5 kHz



Installation & Commissioning: June 2010



APEX :: Flash345 + XIF + XFFTS





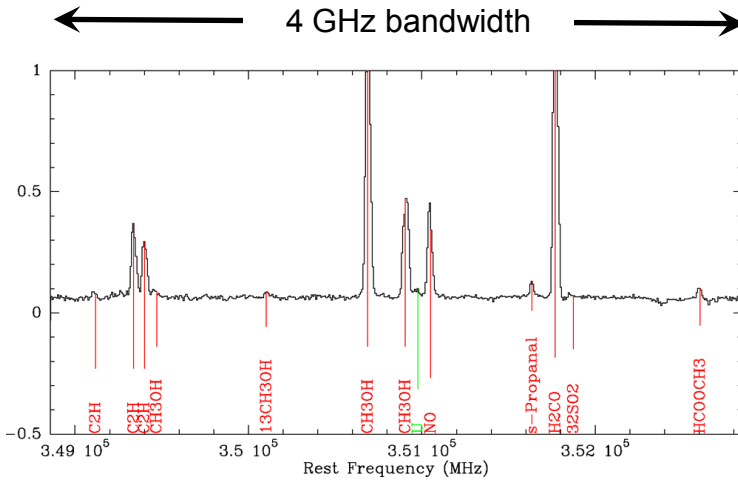
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APEX :: Flash345 + XIF + XFFTS

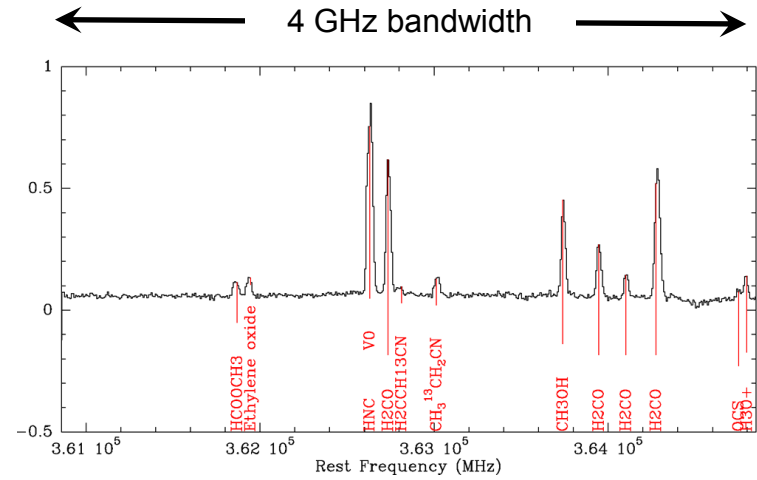


8 GHz of bandwidth in one setup

lower sideband



upper sideband



← 12 GHz spacing →

Flash345: updated receiver with IRAM 2SB SIS mixer



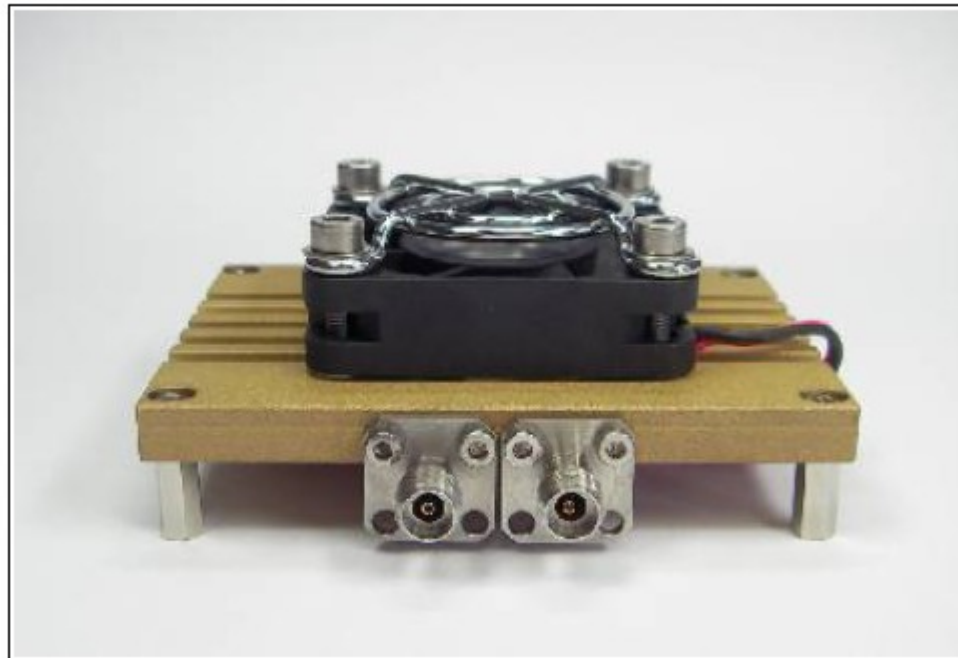


FFT-Spectrometer :: *An Outlook*

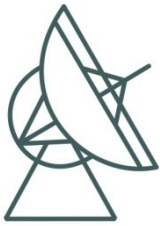
New ADCs: e.g., ADC30 from MICRAM

- 30 GS/s sampling, 15 GHz Nyquist bandwidth
- 6 bit resolution, effective bits (ENOB): > 4.5 @ 14 GHz
- > 20 GHz analog bandwidth, allows direct IF sampling
- But – is this highly interleaved ADC good enough for Radioastronomy ??? We will see...

ADC30 Module

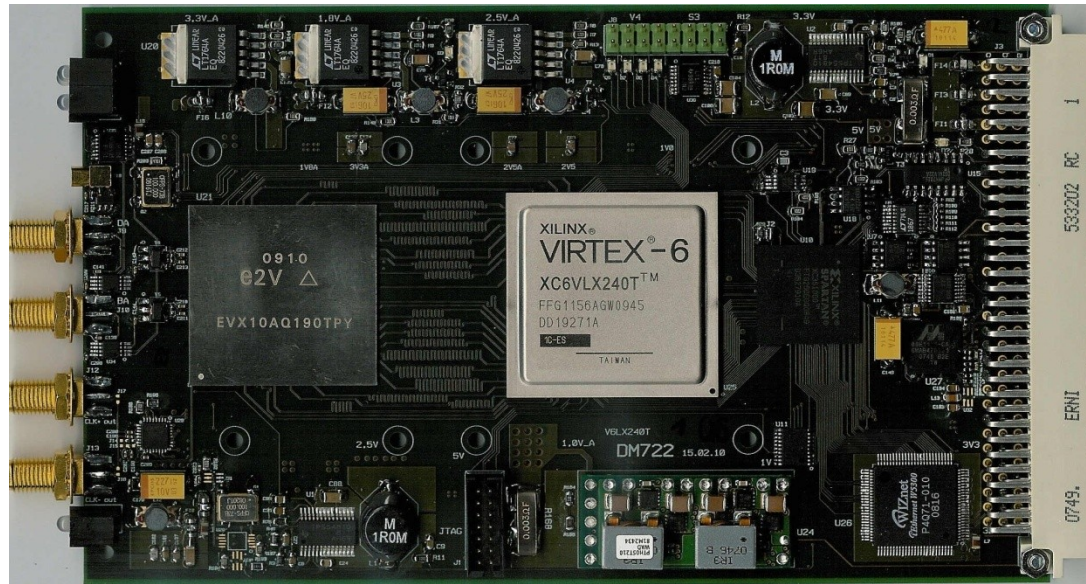


MICRAM



FFT-Spectrometer :: An Outlook

XFFTS2: support for 4 x 10 GBit/s Ethernet



UniBoard

ROACH1/2

PC-Clusters

GPU-Clusters



FFT-Spectrometer :: Summary

Advantages of our new generation of compact FFT spectrometers:

- ✓ FFTS offer high instantaneous bandwidth up to 2.5 GHz with many thousands frequency channels, thus offering wideband observations with high spectral resolution without the complexity of the IF processing in a hybrid configuration.
- ✓ They provide very high stability by exclusive digital signal processing. Allan stability times of > 1000 seconds have been demonstrated routinely.
- ✓ Our optimized polyphase FFT signal processing pipeline provides a nearly loss-free time to frequency transformation with significant reduced frequency scallop, less noise bandwidth expansion, and faster side lobe fall-off.
- ✓ Field-operations of our FFTS over the last 4 years have proven to be very reliable, with calibration- and aging-free digital processing boards, which are swiftly re-configurable by Ethernet for special observation modes.
- ✓ Low space and power requirements – thus safe to use at high altitude (e.g. APEX at 5100-m) as well as on spacecrafts (Sofia) and future satellites (Millimetron?).
- ✓ Production cost are low compared to traditional spectrometers through use of only commercial components.

